Monitoring of Environmentally Hazardous Exhaust Emissions from Cars Using Optical Fibre Sensors

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Abstract
Results are presented for on-board and on-line sensing of vehicle exhaust Gases. The sensor is located downstream of the Diesel Particle Filter of a Fiat Croma and data were simultaneously recorded from reference gas analysis instrumentation.

1. Introduction

Automotive emissions typically consist of water vapour, carbon dioxide (CO_2), carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulphur (SO_x), Hydrocarbons, smoke particles (diameters of 0.05µm to 1µm) and particulate matter (diameters greater than 1µm). Under perfect combustion conditions the following relationship exists:

$$\text{Fuel } (C_xH_x) + \text{Air} \rightarrow CO_2 + H_2O$$

As carbon dioxide (CO_2) and water vapour (H_2O) are both present as trace gases in the atmosphere, no pollution would result from this process. However, in reality perfect combustion does not occur and the following relationship exists as fuel is burnt in an engine:

$$\text{Fuel } (C_xH_x) + \text{Air} \rightarrow CO_2 + H_2O + CO + SO_x + NO_x + PM + C_xH_x + \text{smoke}$$

Research has shown that each of these species is a threat to either human health or the environment [1]. Carbon monoxide (CO) is known to be poisonous to humans at concentrations above 400 parts-per-million. CO_2 is not strictly considered a pollutant as it exists naturally as a trace gas in the atmosphere. It is believed that the relatively high levels of CO_2 produced by combustion are a prime contributor to global warming [2]. CO, HCs and CO_2 have high absorption in the mid-infrared wavelength range [3] whilst NO, NO_2 and SO_2 have strong absorption in the UV and Visisble ranges. All of these gases have been measured in their respective wavelength ranges in this work.

2. Experimental System Descripton

2.1. Gas Concentration Measurement in the Mid Infra Red Range

The experimental set up for measuring CO_2 in the mid infra red region in the exhaust system of the demonstrator vehicle located in the test facility at CRF, Italy is shown in Fig 1. The components of the optical system and comparison to other research have been described in detail by Mulrooney et al [8]. A Dell Latitude D610 notebook equipped with a National Instruments PCIMCIA 6024E data acquisition card was used to acquire the data on site and a Lab View ® Virtual Instrument was used to store these voltages to a file.

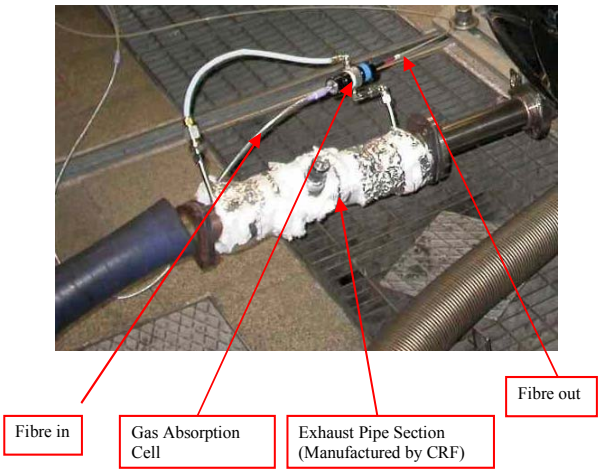

Fig. 1 Mid IR Sensor on the Exhaust Line of the Fiat Croma Demonstrator

2.2. Gas Concentration Measurement in the Ultra Violet Range

The system for measuring the gases NO, NO_2 and SO_2 in the UV range is shown photographically in Fig 2

Fig. 2 The UV Gas Sensor Mounted Underneath the Car

The cell was used to record the levels of NO, NO_2 and SO_2 for a full cycle of the standard acceleration/ deceleration tests as well as standard driving cycles e.g. urban driving cycle with the car mounted on a roller test bench (rolling road) at the test facility of CRF in Turin.

3. Experimental Results

3.1. Mid Infra Red Sensor

The transmission mode optical fibre sensor (referred to as the 'straight sensor' in Fig 3) was connected to the exhaust system of the vehicle as in Fig 1 and the output of the optical fibre sensor and reference instrument were recorded simultaneously as the car was driven on roller test bench in compliance with a standard test known as the NEDC driving cycle. These results are shown in Fig 3.

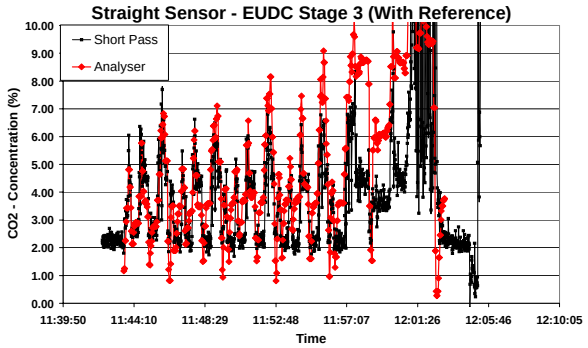

Fig. 3. CO_2 concentration recorded during the NEDC test cycle for the Fiat Croma on the roller test bench. Simultaneous measurements shown for the transmission mode optical fibre sensor and reference instrumentation

It is clear from Fig 3 that the Optical Fibre Sensor is capable of faithfully reproducing the variation of CO_2 concentration over the whole NEDC cycle.

3.1. UV/Vis Sensor

The gas cell of Fig 2 was used to record the levels of NO, NO_2 and SO_2 for a full cycle of the standard acceleration/ deceleration test with the car mounted on a rolling road at the test facility of CRF in Turin. The results of these tests corresponding to NO_2 are shown in Fig. 4.

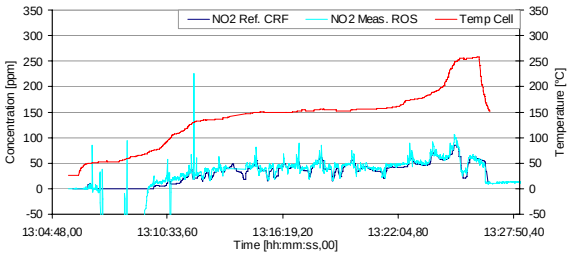

Fig. 4. NO2 Test Results Under the Car With Simultaneous Reference Instruments Recording

It is clear from Fig 4 that the value of NO_2 recorded using the optical fibre sensor faithfully reproduces the values measured on the reference (lab based) instrumentation. The optical fibre sensor has therefore been proved to be capable of measurement within the exhaust of the vehicle.

4. Conclusions

Optical fibre sensors suitable for the detection of exhaust gas emissions have been described in this paper. The development of the sensors are novel as they uses a low cost and compact components coupled to optical fibre, to provide a practical solution for the measurement in the harsh environment of the car exhaust system.

This sensors have proved to be capable of detecting gas concentrations as low as single ppm values for NO, NO_2 and SO_2, and up to 20 % concentration of CO_2 in the exhaust of a car. An analysis of these results using the Reference Forward Model (RFM) [5] and MATLAB have previosly indicated [6] that the measured and theoretical values are in close agreement.

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